LENFEST CENTER FOR SUSTAINABLE ENERGY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

System Analysis of Options to Improve Capture Technology

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Current Options for Capture technologies

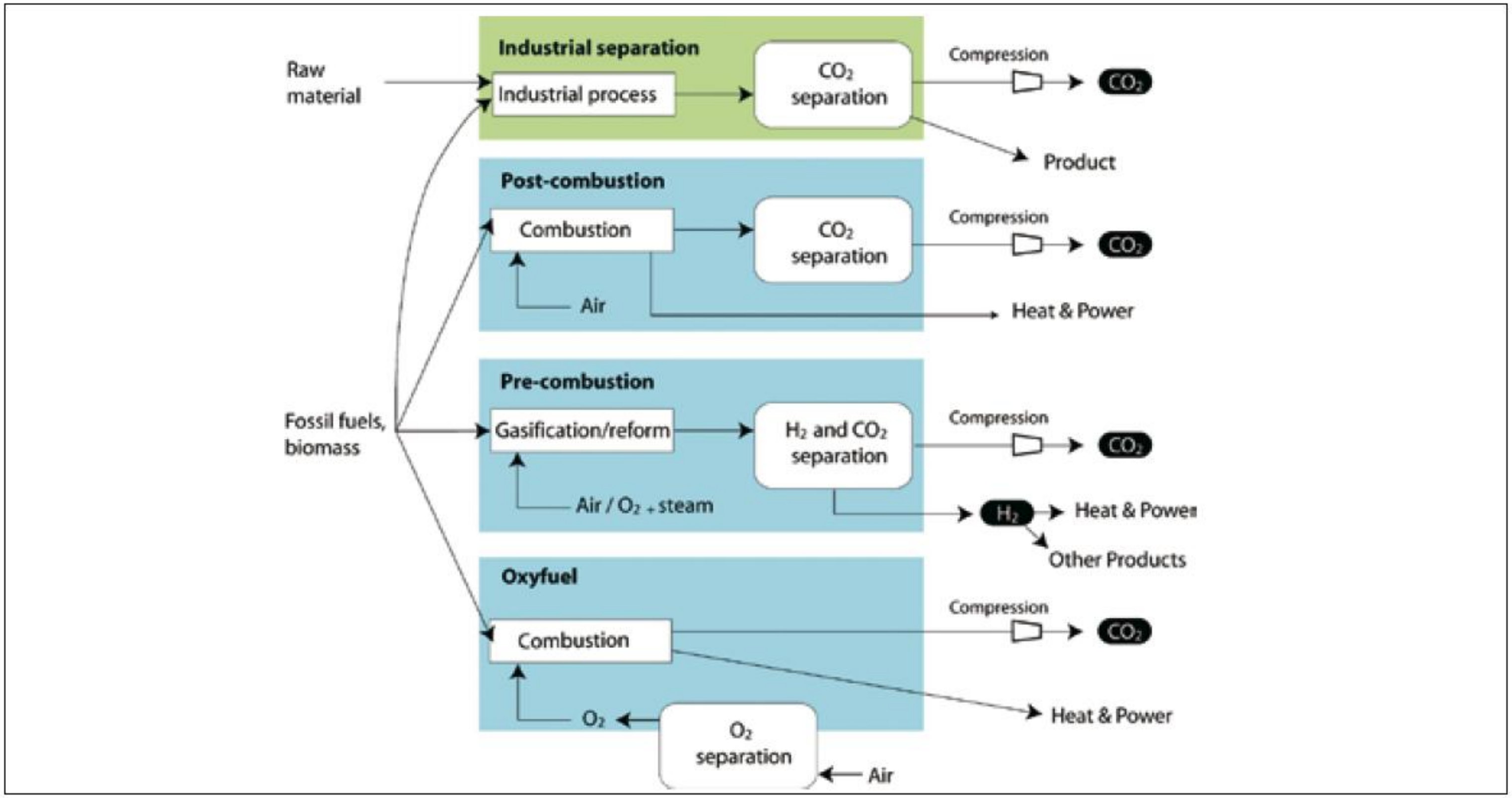


Figure SPM.3. Schematic representation of capture systems. Fuels and products are indicated for oxyfuel combustion, pre-combustion (including hydrogen and fertilizer production), post-combustion and industrial sources of CO_2 (including natural gas processing facilities and steel and cement production) (based on Figure 3.1) (Courtesy CO2CRC).

IPCC, 2005

Novel power plant designs

ZECA, Ziock, Lackner, 2000

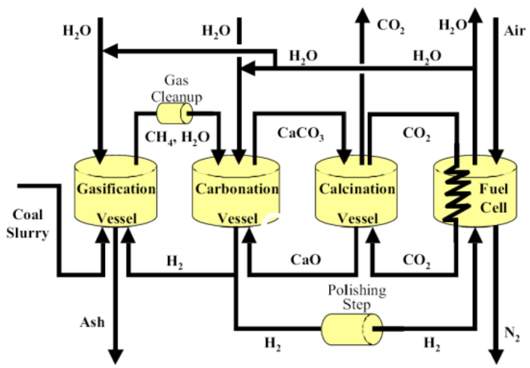


Fig. 4. Schematic of the anaerobic hydrogen production and fuel cell system. Material flows are idealized to the predominant component. The major reactions are as follows:

Gasification Vessel:	$C + 2H_2 \rightarrow CH_4$,	$H_2O(liquid) \rightarrow H_2O(gas)$
Carbonation Vessel:	$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$,	$CaO + CO_2 \rightarrow CaCO_3$
Calcination Vessel:	$CaCO_3 \rightarrow CaO + CO_2$	
Fuel Cell:	$2H_2 + O_2 \rightarrow 2H_2O$	

AZEP, Griffin, 2005

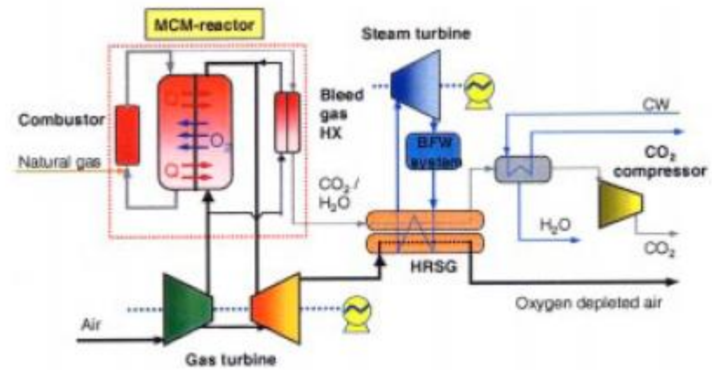


Fig. 1 AZEP process flow sheet

Chemical Looping

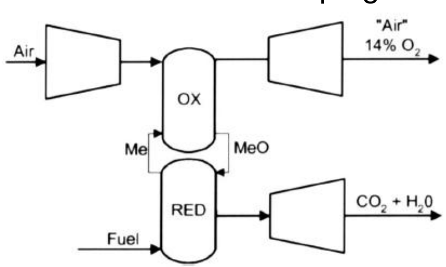
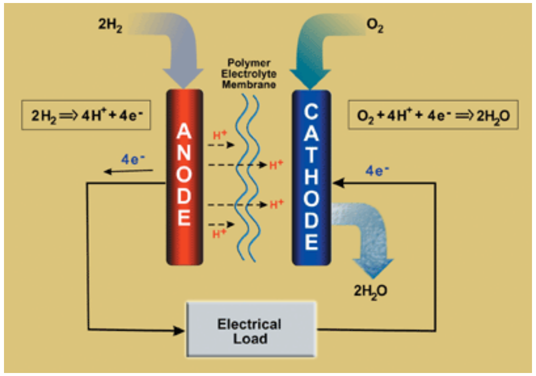
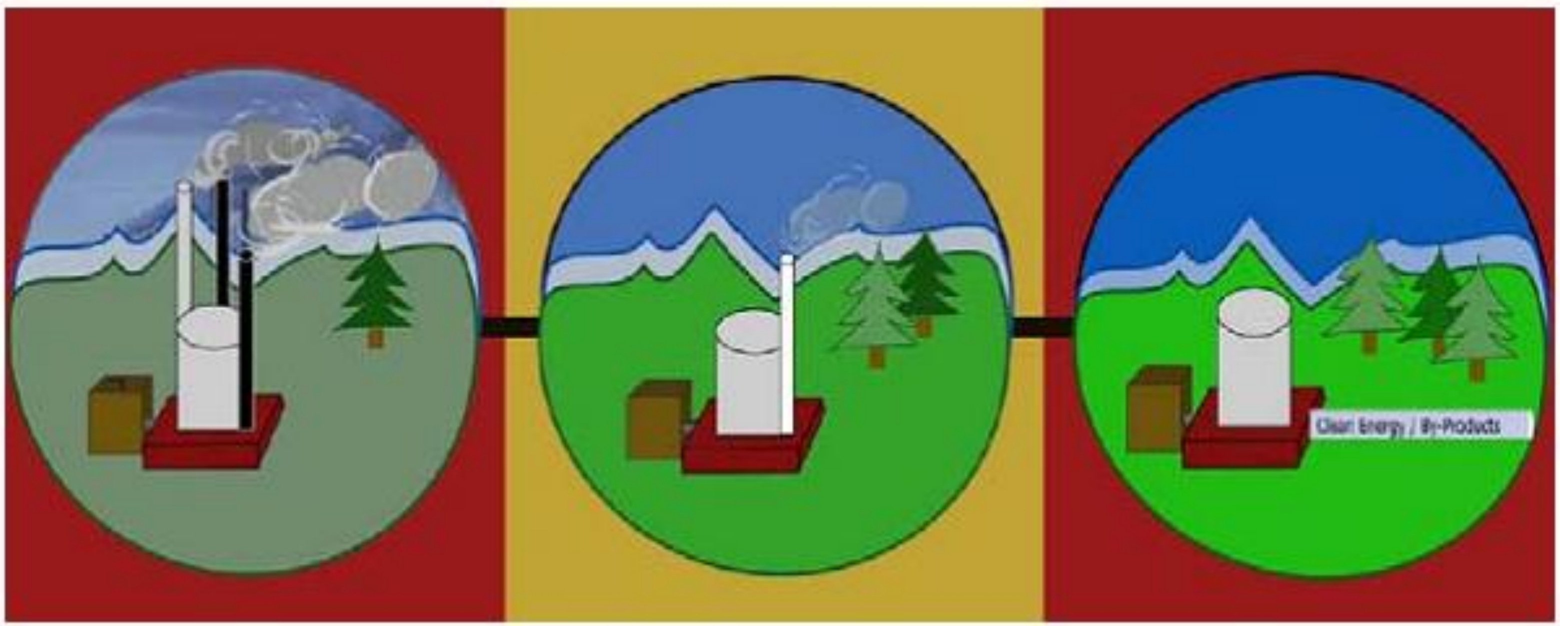


Fig. 1 The chemical looping combustion principle

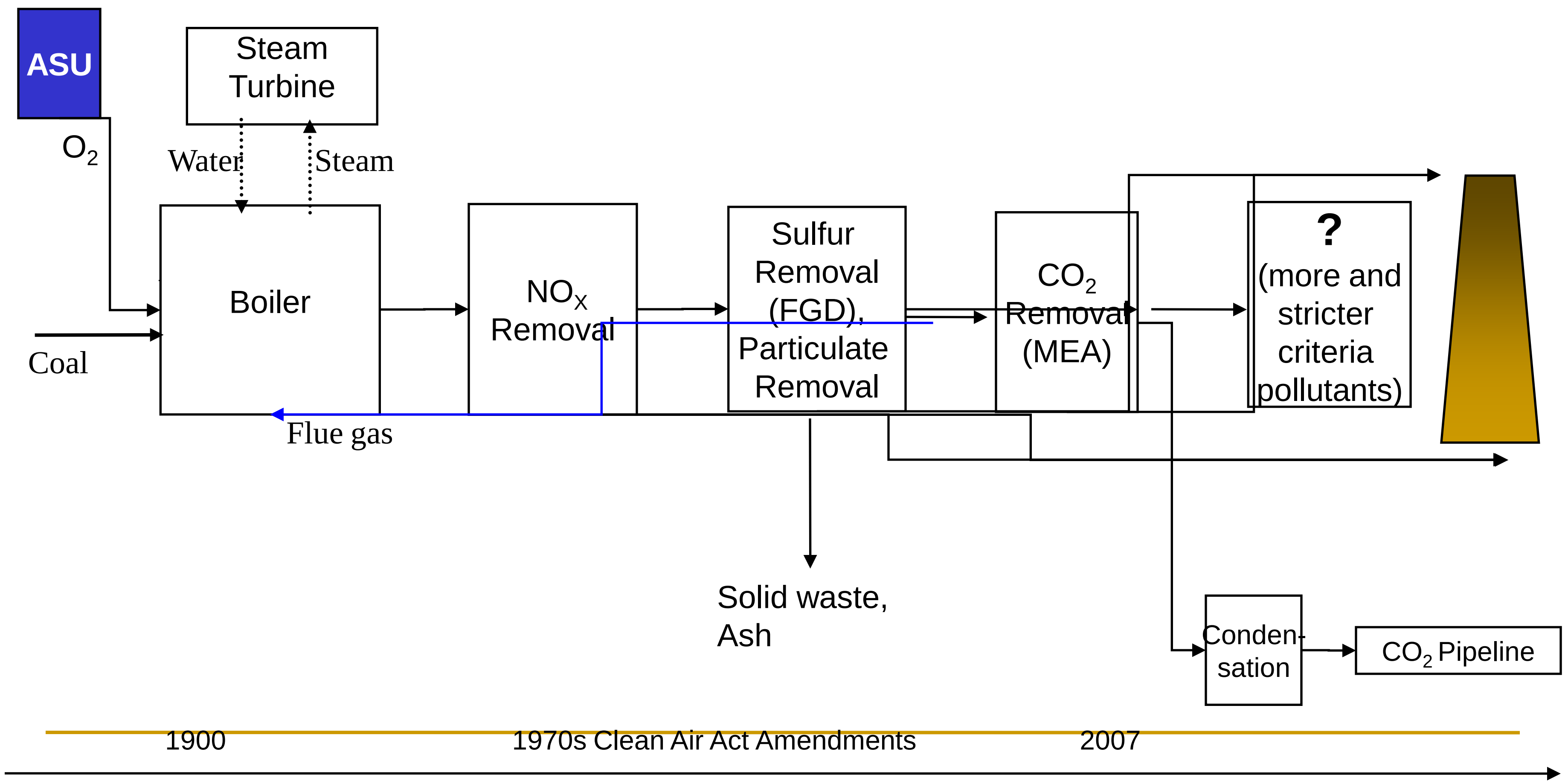
Fuel Cell



Finding a pathway of power plant development



Finding a pathway of power plant development



How do we do it?

Define the problem in mathematics term: solving non-linear integer optimization problem

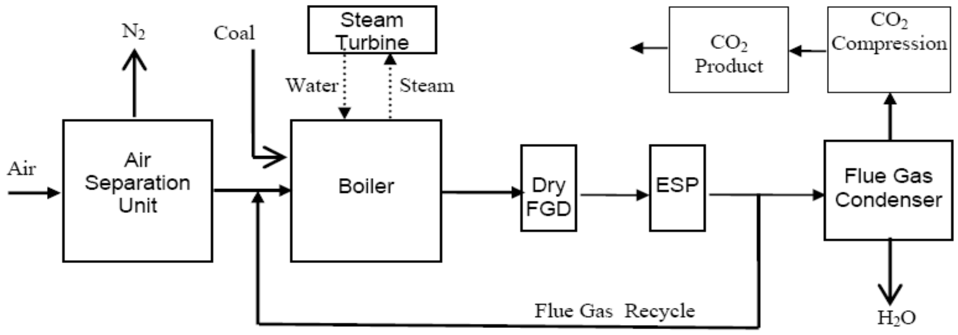
Identify systems/cycles of interest

Find metrics to measure the performance

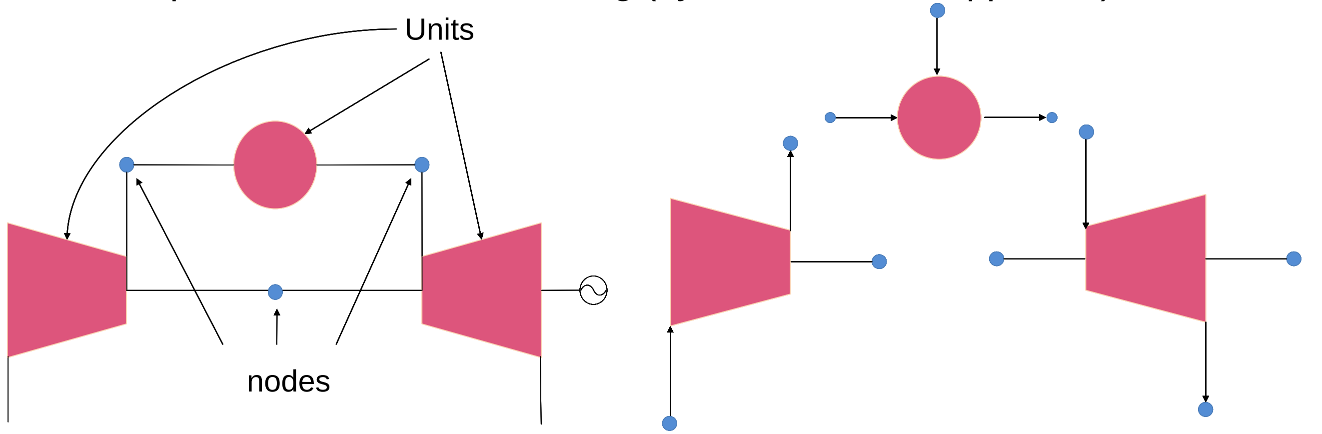
Set the scale for different utility functions

Modular approach for system analysis

Example I: Oxyfuel block diagram



Example II: Gas turbine modelling (dynamic network approach)



Power plant divided in elementary components ((Carcasci, 1996)

TEX model (D. Knuth)

In olden times when wishing still helped one, there lived a king whose daughters were all beautiful; and the youngest was so beautiful that the sun itself, which has seen so much, was astonished whenever it shone in her face. Close by the king's castle lay a great dark forest, and under an old lime-tree in the forest was a well, and when the day was very warm, the king's child went out into the forest and sat down by the side of the cool fountain; and when she was bored she took a golden ball, and threw it up on high and caught it; and this ball was her favorite plaything.

Figure 12. Tiny vertical marks show 'feasible breakpoints' where it is possible to break in such a way that no spaces need to stretch more than their given stretchability.

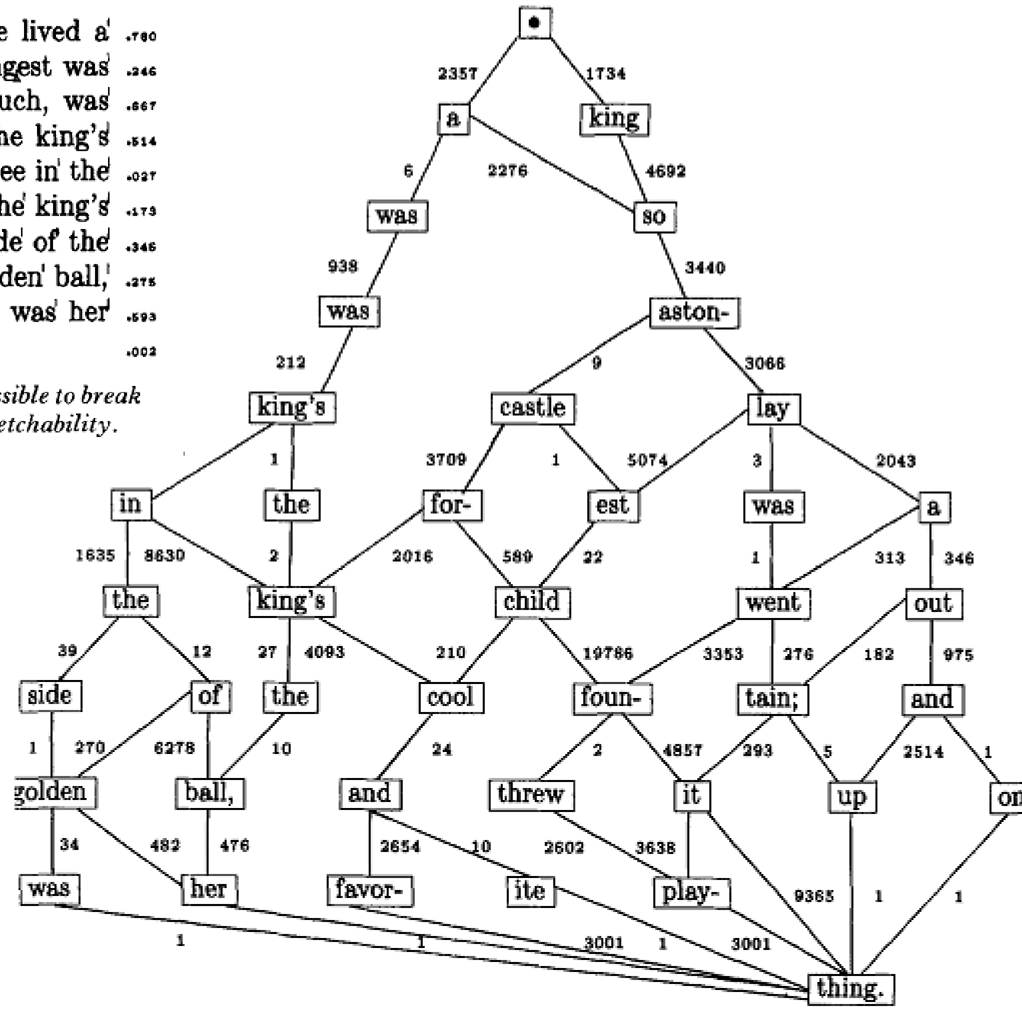


Figure 13. This network shows the feasible breakpoints and the number of demerits charged when going from one breakpoint to another. The 'shortest path' from the top to the bottom corresponds to the best way to typeset the paragraph, if we regard the demerits as distances.

D. Knuth, 1979

Breaking paragraphs into lines

- Problem formulation: using penalty function measured with linear “distance metric“ to describe the difference between the actual layout and the “ideal” layout

Demerit functions for TEX

$$
\begin{array}{ll}
w_i + r_j y_i, & \text{if } r_j \geqslant 0; \\
w_i + r_j z_i, & \text{if } r_j < 0;
\end{array}
$$

$$
\beta_j = \begin{cases} \infty, & \text{if } r_j \text{ is undefined or } r_j < -1; \\ 100|r_j|^3, & \text{otherwise.} \end{cases}
$$

$$
\delta_j = \begin{cases} (1+\beta_j+\pi_j)^2+\alpha_j, & \text{if } \pi_j \geqslant 0; \\ (1+\beta_j)^2-\pi_j^2+\alpha_j, & \text{if } -\infty < \pi_j < 0; \\ (1+\beta_j)^2+\alpha_j, & \text{if } \pi_j = -\infty. \end{cases}
$$

Finding metrics to measure the performance

Demerit Function

Units:

Boiler, Wet FGD, Cold-Side ESP, Hot-Side SCR, Activated Carbon, MEA Scrubber, etc

Demerits of the units:

Efficiencies: $b_{\eta_i} = \left\{ \frac{\eta_i}{1-\eta_i} \right\}^{\beta}$ (β=0.0005)

Costs: $b_{C_i} = \gamma * C_i$ (γ =4)

Total badness: $b_i = b_{\eta_i} + b_{C_i}$

Demerits of the system: compatibility, adding/removing auxiliary units

System efficiencies, emissions, change in the cycle (adding/removing units), etc

$$P_i = b_i + V/I_i + P_{ef(CO2)} + P_{ef(SO2)} + P_{ef(NO2)} + P_{ef(NH3)}$$

A toy test model

Penalties for components

Penalties for Auxiliaries energy consumptions @ beta=0.0005, P=x/(1-x^beta)	Subcritical plant	Sub+FGD	Sub+ESP+FGD	Sub+SCR+ESP+FGD	Sub+SCR+ESP+FGD+Hg	Sub+SCR+ESP+FGD+Hg+Amine	SC+SCR+ESP+FGD+Hg+Amine	USC+SCR+ESP+FGD+Hg+Amine
P_f(Boiler Use)	412.1856051	412.1856051	412.1856051	412.1856051	412.1856051	412.1856051	412.1856051	412.1856051
P_f(Wet FGD)	0	94.28677424	94.28677424	95.37089929	95.37089929	156.6332281	137.4883089	122.3569191
P_f(Cold-Side ESP)	0	0	5.788889937	5.788889937	5.788889937	5.788889937	5.788889937	5.788889937
P_f(Hot-Side SCR)	0	0	0	20.87885654	20.87885654	20.87885654	18.52697239	16.64002819
P_f(Activated Carbon)	0	0	0	0	0.257987006	0.257987006	0.229707326	0.206870801
P_f(Amine Scrubber)	0	0	0	0	0	3363.545822	2823.389171	2420.612124
Sum_P_f(Auxiliaries)	412.1856051	506.4723794	512.2612693	534.2242509	534.4822379	3959.290389	3397.608654	2977.790437

Factored Cost Penalty for each unit (P=gama*Cost) @gama=4								
P_$(Boiler Use)	535.6	524.8	550	546.4	546.4	377.32	402.4	409.6
P_$(Wet FGD)	0	88.4	88.92	89.04	89.04	100.28	94.92	89.84
P_$(Cold-Side ESP)	0	0	21.848	21.228	21.228	21.228	19.784	18.552
P_$(Hot-Side SCR)	0	0	0	36.008	36.008	36.008	33.104	30.608
P_$(Activated Carbon)	0	0	0	0	0.3942	0.38596	0.381	0.3748
P_$(Amine Scrubber)	0	0	0	0	0	477.6	440.4	404.4
P_$(total)	535.6	613.2	660.768	692.676	693.0702	1012.82196	990.989	953.3748

A toy test model (cont.)

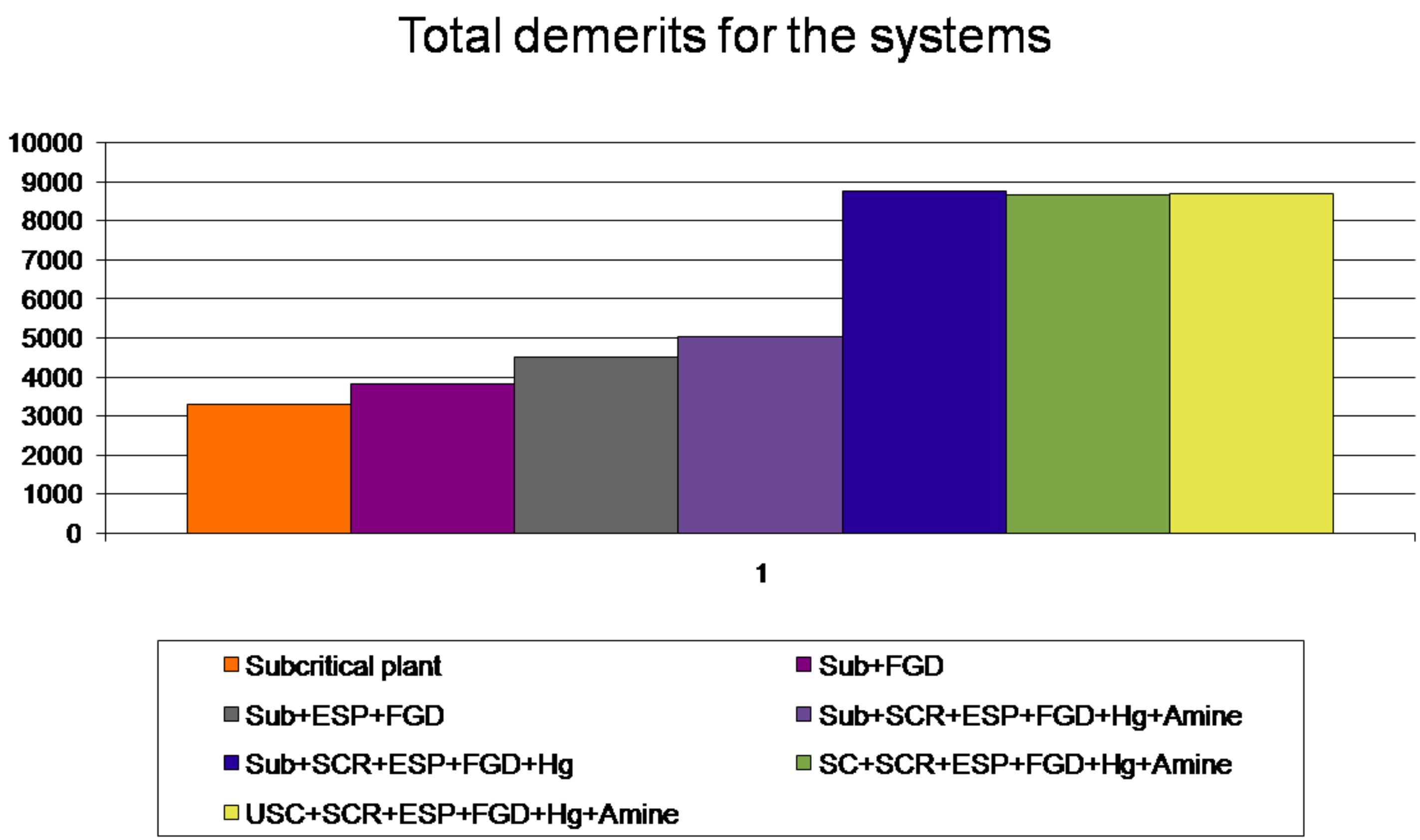
- Penalty for the system

Penalties for Efficiencies, P=-log(eff, base)	Subcritical plant	Sub+FGD	Sub+ESP+FGD	Sub+SCR+ESP+FGD	Sub+SCR+ESP+FGD+Hg	Sub+SCR+ESP+FGD+Hg+Amine	SC+SCR+ESP+FGD+Hg+Amine	USC+SCR+ESP+FGD+Hg+Amine
Penalties for Gross Efficiencies with the base @1.005	190.8070085	190.8070085	190.8070085	190.8070085	190.8070085	190.8070085	169.8351252	150.9211506
Penalties for total auxiliary inefficiencies with the base @1.005	569.1638894	513.4313446	508.929584	495.1980865	494.7246516	219.8707086	236.9021304	251.8210819

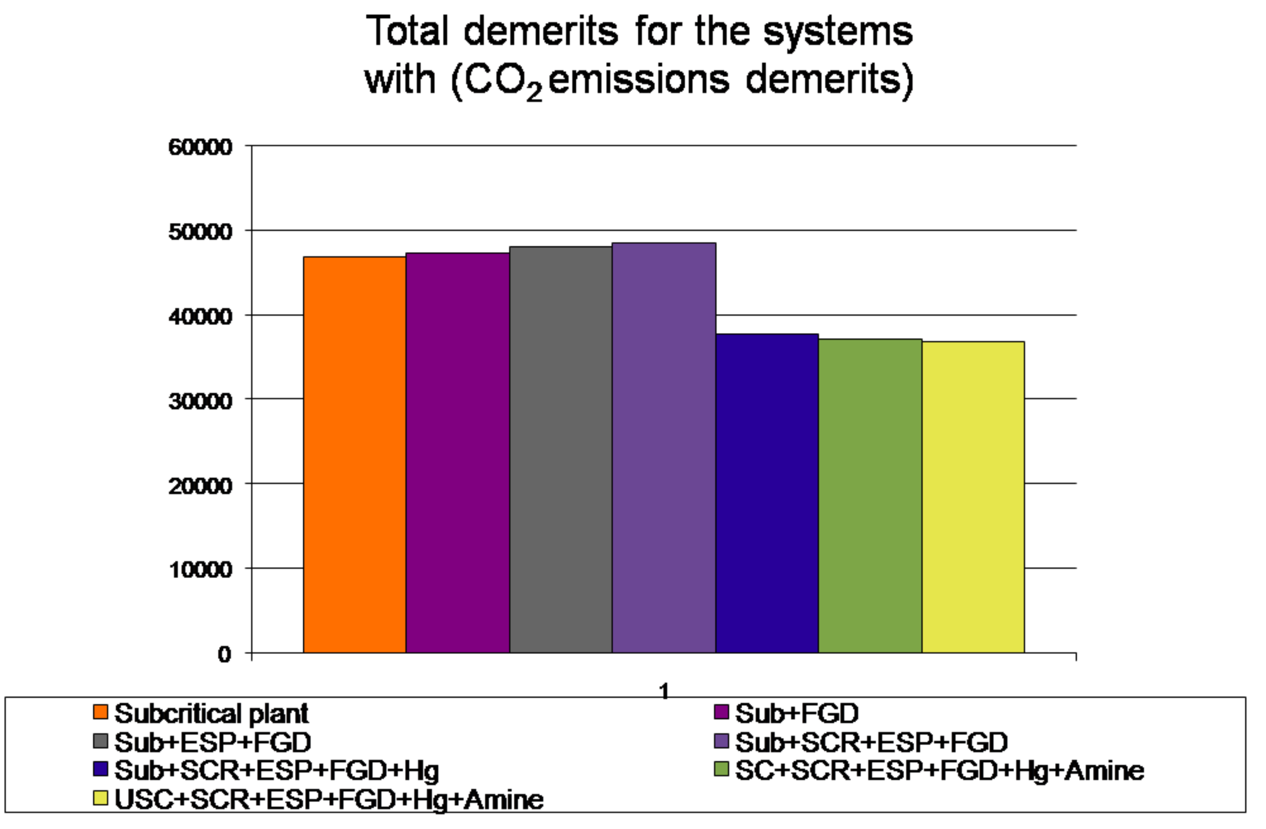
Penalty for emissions	Subcritical plant	Sub+FGD	Sub+ESP+FGD	Sub+SCR+ESP+FGD	Sub+SCR+ESP+FGD+Hg	Sub+SCR+ESP+FGD+Hg+Amine	SC+SCR+ESP+FGD+Hg+Amine	USC+SCR+ESP+FGD+Hg+Amine
P_ef(CO2)	434.5347	434.5347	434.5347	434.5347	434.5347	289.4393	285.1184	281.3173
P_ef(SO2)	317.6428	317.3991	317.6428	317.3991	317.3991	143.7769	142.6967	141.7338
P_ef(NO2)	231.0318	231.0318	211.6197	185.4430	185.4430	180.5976	178.9009	177.4009
P_ef(NH3)	0.0000	0.0000	0.0000	171.2484	171.2484	265.4635	261.8116	258.5946
Total Penalties for emissions	983.2092	982.9655	963.7971	1108.6251	1108.6251	879.2774	868.5276	859.0465

Total Penalties for Add/Removal of Units	0	500	1000	1500	2000	2500	3000	3500

A toy test model (cont.)



A toy test model (cont.)



Future Work

- Assess new concepts for energy conversion from coal to electricity that eliminate stack emissions that provide a means for capturing and sequestering carbon dioxide produced in the process.

- Devise an multidimensional, weighted-penalty, assessment methodology to assess system performance;

- Develop engineering and process models for "zero-emission" coal plant designs;

- Conduct process evaluations and system assessments using penalty-based optimization model.

Thank you